SOUTHERN GREAT PLAINS EXPANSION OF GLYPHOSATE RESISTANT BRASSICA NAPUS L.: MANAGEMENT AND MAPPING

A Thesis

by

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ABSTRACT

Brassica napus L. production has become more predominant in the United States. Increased yield in rotational systems and the increased market for this crop have created a potential for *B. napus* expansion into regions where it is not currently utilized. This has created a gap of knowledge that is necessary for proper management and implementation of this crop. The objectives of this project were to determine potential controls for volunteer weed issues found in *B. napus* cropping systems, as well as control of volunteer/weed *B. napus* in wheat cropping systems that have been incorporated in the southern latitudes of the Great Plains. A secondary objective was the refinement and potential implementation of a new precision farming tool Terrestrial Laser Scanning (TLS). Findings suggest that application of Potassium salt of Glyphosate had significant ($P \leq 0.05$) impact on weed control in *B. napus* cropping systems and chemicals such as Flufenacet and Bromoxynil were found to be best in control of volunteer/weed *B. napus* in a *Triticum aestivum* L. system with high significance ($P \leq 0.05$) when compared to untreated control trials. TLS was found to be effective in regards to discriminating monocots in a *B. napus* cropping system or discrimination of *B. napus* in a *Triticum aestivum* L. cropping system using a combination of intensity value and structural characteristics.

DEDICATION

To my Grandparents

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NOMENCLATURE

B. napus	Brassica napus L.
Canola	*Brassica napus* L.
Mustard	*Brassica juncea* L.
Ryegrass	*Lolium perenne* L.
Wheat	*Triticum aestivum* L.

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CHAPTER I

INTRODUCTION

Global *Brassica napus L.* production has grown rapidly over the past 40 years. It has risen from the sixth largest oil crop around the world to second(USDA, 2012). Production levels have increased globally and *B. napus* now accounts for 10-15 percent of world oil crop production (USDA, 2012). In the US alone production levels have reached 40 times the levels found in 1991 (USDA, 2012). Not only has production of the crop risen over the decades, demand has also driven the market value of the crop to new highs. *B. napus* production prices have doubled in the past 20 years (USDA, 2012). Due to these incentives *B. napus* has become more incorporated south of its normal latitudes in North America. With increased information about cultivar performance and their adaptability to specific growing regions this movement can be expected to continue (Brown et al., 2008).

Though this potential has created an opportunity for *B. napus* expansion into the southern Great Plains, little is known about weed management within these crops as well as its control as a volunteer weed in the region (Brown et al., 2008). Further issues with volunteer control could potentially arise in that most agricultural systems in the northern Great Plains have incorporated the use of herbicide resistant Canola crops (Beckie et al., 2003). This type of crop would potentially be incorporated in the southern latitudes of the Great Plains. Though herbicides have been used to control such weed activity in agricultural systems and have been one of the most important advances in agriculture

(Blackshaw et al., 2006; Derksen et al., 2002), further study is required to better understand and assess methods for control in these regions as well as assess the management of other weeds in an herbicide-tolerant canola system.

Weed management studies in these newer systems should incorporate the use of precision farming for identifying weed occurrences and their densities in a field (Blackshaw et al., 2006; Shaw, 2005; Wiles, 2005). The current method of assessing the effectiveness of weed management through herbicide control is either a rating system that collects visual estimates of biomass characteristics or a laborious weed pull-and-count method (Vanhala et al., 2004). Developing new technologies for better more accurate estimates would assist not only in the ability to begin a *B. napus* cropping culture in the southern latitudes of the Great Plains, but would also advance current weed management practices.

The objectives of this project were to 1) determine potential controls for weed issues found in *B. napus* cropping systems, as well as 2) control of volunteer/weed canola in wheat cropping systems that have already been established in the southern latitudes of the Great Plains; and 3) the refinement and potential implementation of a new precision farming tool, Terrestrial Laser Scanning (TLS).

CHAPTER II

STUDY SITES

Two experimental locations were selected for characterization of herbicide efficacy in varying moisture regimes. The first location was located at the Texas AgriLife Research Station in McGregor, Texas. The field site is located approximately 8 km south west of McGregor, Texas, at coordinate position 31° 21’ 59.22” North by 97° 26’ 59.07” West. The second site is located at the Texas A & M University Research Farm near College Station, Texas. The field site is approximately 12 km south west of College Station, Texas at coordinate position 30° 30’ 38.34” North by 96° 25’ 09.10” West (**Appendix A**).

McGregor, Texas

The site receives precipitation ranging from 660 to 860 mm of rainfall annually. The mean annual temperature ranges from 18°C to 24°C with 230 to 250 frost-free period days. The site elevation is roughly 2440 m above sea level.

Ecoregion

This study site is located within the Texas Blackland Prairies as classified by the Ecoregions of the United States (Bailey et al., 1994). Its sub classification is Northern Blackland Prairie. The Northern Blackland Prairie formed on Cretaceous deposits developing a mostly fine-textured, dark, calcareous, and productive Vertisol (Bailey et al., 1994). The soil temperature regime for this area is Thermic with mean annual soil temperature ranging from a low of 15°C to a high of 22°C (USDA, 2013). The soil moisture regime which is of primary importance for this study is found to be Ustic in which the soil moisture is limited but is present at a time when conditions are suitable for plant growth (USDA, 2013).

Soil Description

The study site is located on Slidell clay with 0 to 2 percent slopes (USDA, 2013). These soils are found on toe slopes of ridges and parent materials consist of clayey slope alluvium (USDA, 2013). The soils were moderately well drained with a high available water capacity at 25 cm and the water table located greater than 200 cm from the soil surface (USDA, 2013). The typical profile of these soils consisted of clay from 0 to 50 cm, clay from 50 to 95 cm, and silty clay 95 to 180 cm in depth (USDA, 2013).

Soil Properties

For our study, limiting factors of plant growth must be noted in order to account for soil bias that may attribute to differences between sites. Soil properties are for the areas ranging from 0 to 100 cm in soil depth. Slidell clays for our site have a slightly alkaline pH of 7.9 using a 1:1 water method (USDA, 2013). The cation-exchange capacity for this soil is 50 milliequivalents per 100 grams (USDA, 2013). Calcium carbonate plays a role in nutrient availability in soils. For Slidell clays there is 20% calcium carbonate by weight in the fraction of the soil less than 2 millimeters in size (USDA, 2013).

Cropping History

In communication with the current farm manager at this site, the general lacking nutrients in the soil include nitrogen and potassium. In most occurrences, phosphorus is sufficient or in excess. The crop rotation history for this site includes the production of wheat in winter months and corn during the summer months. Crop production prior to planting our trials included a corn variety.

College Station, Texas

The site receives precipitation ranging from 1000 to 1300 mm of rainfall annually, and the moisture was also regulated using a Valley Linear irrigation unit in which 15 mm of water were applied to the soil 12 hours prior to planting and when crops began to show signs of water stress. Its mean annual temperature ranges from 18°C to 20°C with 225 to 280 frost-free period days. The site elevation is roughly 1000 m above sea level.

Ecoregion

This study site is located within the East Central Texas Plains as classified by the Ecoregions of the United States (Bailey et al., 1994). Its sub classification is Southern Post Oak Savanna (Bailey et al., 1994). The soil temperature regime for this area is Thermic with mean annual soil temperature ranging from a low of 15°C to a high of 22°C (USDA, 2013). The soil moisture regime for this area is Udic in which the soil moisture control section is not dry in any part for as long as 90 cumulative days per year (USDA, 2013).

Soil Description

The study site is located on Belk clay with 0 to 1 percent slopes (USDA, 2013). These soils are found on flood plains and parent materials consist of clayey over loamy alluvium of Holocene age derived from mixed sources (USDA, 2013). The soils are well drained with a high available water capacity at 25 cm and the water table located greater than 200 cm from the soil surface (USDA, 2013). The typical profile of these soils consists of clay from 0 to 15 cm, clay from 15 to 56 cm, and stratified silt loam to very fine sandy loam from 56 to 180 cm (USDA, 2013).

Soil Properties

Soil properties for this area are in the range of 0 to 100 cm in soil depth. Belk clays in this site have an alkaline pH of 8.2 using a 1:1 water method (USDA, 2013). The cation-exchange capacity for Belk clays at this study site is 27.3 milliequivalents per 100 grams (USDA, 2013). Nutrient availability is directly related to calcium carbonate in soils and for this site the percent calcium carbonate by weight in the fraction of the soil that is less than 2 millimeters in size is 13 percent (USDA, 2013).

Cropping History

In communication with farm personnel at this site the general lacking nutrient of the soil has been nitrogen with phosphorus and potassium being found in sufficient amounts. The previous crop productions on this site included cotton and soybean in the summer months and wheat during the winter months.

CHAPTER III

WEED/VOLUNTEER CONTROL IN GLYPHOSATE RESISTANT BRASSICA NAPUS L.

Synopsis

Due to the knowledge of Genetically Modified Herbicide-Tolerant (GMHT) crops and the potential for uses in future incorporations to systems in the Southern Great Plains two primary questions were posed. The first was which herbicides would be the most effective to control weeds in a Glyphosate resistant canola cropping system, and second which herbicides will produce the lowest phytotoxicity? To answer these questions the following objective was set. The objective would be through herbicide efficacy testing, derive which of eight commonly used herbicides would have the greatest weed/volunteer control and lowest phytotoxicity. Based on knowledge of the eight herbicides, their history of use, and the knowledge of the resistant crop, we hypothesized that Potassium salt of Glyphosate would be the most effective chemical for control on weeds in a Glyphosate resistant canola cropping system due to its broad spectrum of control. We also hypothesized that Potassium salt of Glyphosate would have the least phytotoxic effect because of the crops resistance to the chemical mode of action. Through testing of the various chemicals it was discovered that the herbicide Potasium Salt of Glyphosate was the most significant control of weeds in a GMHT canola cropping system and also showed the least phytotoxic response.

Introduction

Glyphosate is a nonselective, broad-spectrum herbicide that is highly effective against the majority of annual and perennial grasses and broadleaved weeds (Pline-Srnic 2006). Glyphosate affects the plant by inhibiting the 5-*enol*-pyrubylshikimate-3-phosphate synthase (EPSPS) process in the Shikimate pathway. This synthase is used to catalyze Shikimate 3-phosphate and phosphoenolpyruvate (PEP). Glyphosate is a competitive inhibitor of PEP and a non-competitive inhibitor to Shikimate 3-Phosphate therefore reducing the catalyzing step in the pathway. The Shikimate pathway produces Chorismate, a precursor of the aromatic amino acids (Pline-Srnic, 2006). Chorismate is vital to a plant's success as it is the key component to the production of Tryptophan, Phenylanine and Tyrosine, all of which are essential amino acids that act as building blocks in protein biosynthesis (Pline-Srnic, 2006).

Glyphosate has very favorable environmental and safety characteristics such as rapid soil binding, and thus resistance to leaching, rapid biodegradation, as well as extremely low toxicity to mammals, birds, and fish (Malik et al., 1989; Pline-Srnic, 2006). Along with its effectiveness in weed control, these characteristics are what make it an ideal choice for use in resistant crops (Pline-Srnic, 2006).

By implementing the use of Glyphosate resistant crops, the grower is provided an additional mode of action that was not previously available. This would be achieved by allowing the growers to treat on an "as needed basis" which would reduce the dependence on pre-emergence herbicides (Pline-Srnic, 2006). Benefits provided by the use of glyphosate resistant crops has allowed for the development of new mechanisms for implementation (Pline-Srnic, 2006). A potential benefit of Genetically Modified Herbicide-Tolerant (GMHT) crops is an increased efficiency of broadleaf weed control by allowing both a reduction and delay in herbicide application (Begg et al., 2006; Firbank and Forcella, 2000); this would enhance arable diversity and lead to a reduction in production cost (Begg et al., 2006; Tolstrup et al., 2003). Canadian growers have rapidly adopted herbicide-tolerant canola for several reasons; of which include easier and improved weed control, higher seed yield, and higher financial net returns based primarily on the higher yield, reduced dockage, and lower herbicide costs (Beckie et al., 2003; Devine and Buth, 2001).

Materials

These trials were planted with DK 4410 Round-Up Ready Canola (*Brasssica napus* L.) as the primary crop. We planted 3 weed/volunteer species along with the canola including a *Triticum aestivum* L. variety (Armour wheat), a *Brassica Juncea* L. variety (Pacific Gold mustard) and a *Lolium perenne* L. variety (Gulf ryegrass). There were 8 herbicides used in the treatment and 1 control (**Table 1**).

Table 1. Chemicals applied in Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial including licensed product name as well as product supplier and supplier location.

Chemical	Product	Product Supplier and Location	
Trifluralin	Treflan® 4D	Dow AgroSciences LLC	Indianapolis, IN
1,2,4-Trimethylbenzene	Dual Magnum®	Syngenta Crop Protection, LLC	Greensboro, NC
Pendimenthalin	Prowl®H2O	BASF Ag Products	Florham Park, NJ
Carfentrazone-ethyl	Aim® EC	FMC Corporation Agricultural Products Group	Philadelphia, PA
Clethodim	Select® 2EC	Valent U.S.A. Corporation	Walnut Creek, CA

Table 1. Continued

Chemical	Product	Product Supplier and Location	
Quizalofop P-ethyl	Assure® II	Dupont Crop Protection	Wilmington, DE
Potassium salt of Glyphosate	Roundup WeatherMax®	Monsanto Company	St. Louis, MO
Sethoxydim	Poast®	BASF Ag Products	Florham Park, NJ

Methods

Experimental Design

Treatments were applied in a randomized split plot design in a 16.5 m x 31.5 m field section. The main plots are based on the eight herbicide treatments and the untreated check for a total of nine plots which were replicated four times for a total of 36 main plots. Each main plot was 1.5 m x 6 m separated by a .25 m buffer between treatments and 1.5 m buffer between replicates. Each treatment is replicated four times. The main plots have four subset plots to create the split plot design. The subsets include, 1 crop (*B. napus* alone) planted at .91 kg ha^{-1}and 3 crop:volunteer combinations with each species in the combination being planted at .91 kg ha^{-1} (*Brassica napus* L.:*Brassica Juncea* L., *Brassica napus* L.:*Lolium perenne* L., *Brassica napus* L.:*Triticum aestivum* L.) Visual representation of this design can be found in **Figure 1**. Each main plot was planted in 10 rows with .18 m spacing between rows of *B. napus* and the volunteer/weed species were planted perpendicular to main plots at 10 rows spaced at .18 m between rows. Trials were provided Nitrogen fertilizer at a rate of 100 kg ha^{-1} and sulphate at a rate of 30 kg ha^{-1} at the 4 leaf stage of the canola crop.

Figure 1. Split plot design used in the Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial. The red box illustrates a main plot, and the four boxes within the main plot illustrate the subset plots (i.e. canola/wheat; canola/mustard; canola/rye grass; canola). Images above the plot layout illustrate the planting combination applied in this trial.

These trials were performed in two consecutive years (2011-2012 and 2012-2013) and were planted in mid-November (November 15 2011 and November 12 2012). The trials were planted in a the two study site locations with the McGregor crops planted after a corn rotation and the College Station crops planted after a cotton rotation.

Herbicide Application

Herbicide application was completed across each main plot and applied to all four replicates. The treatment consisted of the labeled application rate for each active ingredient per hectare (ai ha^{-1}) diluted in .175 liters of water (48.6 L ha^{-1}) (**Table 2).** Several treatments also included labeled surfactants (**Table 2)**.

Table 2. Chemicals applied to the Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial including the specific rates and mix components per treatment. Abbreviations: kg, Kilograms; ai, active ingredient; ha, hectare. Surfactant rate applied as (V/V%).

Chemical	**Rate**
	kg ai ha^{-1}
Untreated Check	
Trifluralin	0.04
1,2,4- Trimethylbenzene	1.41
Pendimenthalin	1.06
Carfentrazone-ethyl	0.11
Non Ionic Surfactant	.25
Quizalofop P-ethyl	0.06
Clethodim	0.28
Potassium salt of Glyphosate	1.06
Sethoxydim	1.05

The herbicide was applied using a 1.5 m walking boom sprayer set at 55 psi with four standard flat fan nozzles at 0.25 m spacing. The boom was held at 0.25 m above soil surface and moved through the plot at a pace of 1.2 m s^{-1}.

Efficacy Rating

Efficacy ratings were conducted using a visual rating method in which the observer measures the percent weed control in regards to mortality (complete necrosis or abscission) for each herbicide and its percent of phytotoxicity (Complete necrosis or abscission) to the crop (Vanhala et al., 2004). This is done by determining percent mortality in relation to an untreated check plot. The percent control and phytotoxicity will be measured using a scale of 0 – 10 where zero is equivalent to 0% percent mortality and 10 is equivalent to 100% mortality. Also if there were 1-2 plants still visible a 9.9 rating was given due to the fact that control was not 100% yet known to be greater than 10%. This method increases the accuracy of rating systems, since the ability to determine a change of 1% is difficult for a researcher to determine. At 10% the researcher has the ability to stay within the bounds of variability.

These ratings were performed at various intervals set at 7 days after application (DAA), 14 DAA, 21 DAA, 35 DAA, 49 DAA, 70 DAA. **Table 3** lists the actual dates for these rating periods for both years. Actual rating days vary ± 3 days from the seven or fourteen day interval in which ratings were to occur due to weather or logistical issues.

Table 3. Days according to site and year in which ratings were taken for the Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial. Days vary ±3 days of days after application due to weather or logistics.

Site	Year	Day After Application					
		7 DAA	14 DAA	21 DAA	35 DAA	49 DAA	70 DAA
College Station	**2012**	Jan. 4	Jan. 11	Jan. 18	Feb. 3	Feb. 16	Mar. 1
College Station	**2013**	Dec. 12[1]	Jan. 4	Jan. 10	Jan. 24	Feb. 7	Feb. 21
McGregor	**2012**	Dec. 29[2]	Jan. 5	Jan. 10	Jan. 26	Feb. 9	Feb. 23
McGregor	**2013**	Jan. 28	Feb. 4	Feb. 11	Feb. 25	Mar. 11	Mar. 25

Yield Analysis

The herbicide treatments may have an adverse effect on the canola crop. Consequently, phytotoxicity levels of all herbicides applied were also measured by harvesting crops in each 1.5 m x 1.5 m subset plot to determine the seed yield. Seed yield was determined by weighing and the mean subset plot weight was compared between herbicide treatments.

Efficacy Rating Results

Results are presented as an interpretation across sites and years with relevant information as to mode of action and significance of control in relation to untreated checks.

[1] Data collected in 2012 for 2013 harvest season.
[2] Data collected in 2011 for 2012 harvest season.

Results

Wheat Control

The most rapid response at both locations across both years was associated with the chemical Trifluralin, a pre-emergence herbicide (**Tables 4, 5, 6 and 7**). Trifluralin prevents growth by inhibiting root development through the interruption of mitosis (Grover et al., 1997). Due to this mode of application and action, the control of wheat was the most rapid. Though the response is rapid and the control of wheat is significantly different ($P \leq .05$) than that of the untreated checks in rating 7 DAA, its overall control is less than that found in other chemicals across sites and years. This can be attributed to the fact that Trifluralin is highly volatile (Parochetti and Hein, 1973) and is also susceptible to photodecomposition (Grover et al., 1997). It can be inferred that chemical loss due to photodecomposition and volatilization would cause for insufficient residual herbicide for control of late emerging weeds (Chauhan et al., 2006). Since the incorporation of Trifluralin in our trials occurred prior to planting, it is possible that chemical was lost between incorporation and planting. This is even more evident when comparing this effect across years. In 2012 Trifluralin incorporation was done fourteen days prior to planting while in 2013 incorporation was done seven days prior to planting. It is evident that the response of control was greater when the chemical was allowed less time for volatilization and photodecomposition.

Table 4. Efficacy control data of wheat (*Triticum aestivum* L.)per chemical treatment in the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2012. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

College Station Texas 2012		**Wheat Control**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		2.50c	0.00b	12.50a	25.00b	24.75bc	27.50abc
Trifluralin	0	52.50ab	30.00ab	20.00a	42.50ab	40.00abc	52.50abc
1,2,4- Trimethylbenzene	2	7.50c	0.00b	10.00a	10.00b	12.50bc	32.50abc
Pendimenthalin	2	7.50c	0.00b	0.00a	0.00b	0.00c	0.00c
Carfentrazone-ethyl	2	60.00a	35.00a	45.00a	89.50a	85.00ab	94.50a
Quizalofop P-ethyl	2	5.00c	2.50b	10.00a	42.50ab	45.00abc	50.00abc
Clethodim	2	5.00c	0.00b	0.00a	0.00b	0.00c	2.50bc
Potassium salt of Glyphosate	2	25.00bc	15.00ab	37.50a	100.00a	75.00ab	75.00ab
Sethoxydim	2	10.00c	2.50b	25.00a	100.00a	100.00a	100.00a

Table 5. Efficacy control data of wheat (*Triticum aestivum* L.) per chemical treatment in the McGregor Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2012. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

McGregor Texas 2012		**Wheat Control**[b]					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		17.50a	12.50a	12.50a	7.50c	0.00b	0.00b
Trifluralin	0[c]	32.50a	22.50a	42.50a	37.5bc	30.00b	30.00b
1,2,4- Trimethylbenzene	2	0.00a	0.00a	7.50a	0.00c	0.00b	0.00b
Pendimenthalin	2	0.00a	2.50a	12.50a	2.50c	0.00b	0.00b
Carfentrazone-ethyl	2	12.50a	20.00a	12.50a	2.50c	0.00b	0.00b
Quizalofop P-ethyl	2	7.50a	0.00a	20.00a	77.50ab	84.75a	84.75a
Clethodim	2	22.50a	25.00a	0.00a	20.00c	15.00b	15.00b
Potassium salt of Glyphosate	2	7.50a	10.00a	30.00a	97.00a	94.75a	94.75a
Sethoxydim	2	5.00a	10.00a	15.00a	99.00a	100.00a	100.00a

Table 6. Efficacy control data of wheat (*Triticum aestivum* L.) per chemical treatment in the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 7 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

College Station Texas 2013		**Wheat Control**[b]					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00a	0.00b	0.00c	0.00c	0.00c	0.00c
Trifluralin	0[c]	42.50a	57.50a	80.00a	79.50ab	79.50a	89.75a
1,2,4- Trimethylbenzene	2	0.00a	0.00b	0.00c	5.00c	5.00c	15.00c
Pendimenthalin	2	0.00a	0.00b	0.00c	0.00c	0.00c	0.00c
Carfentrazone-ethyl	2	2.50a	2.50b	0.00c	0.00c	0.00c	0.00c
Quizalofop P-ethyl	2	0.00a	55.00a	87.50a	94.75a	99.00a	96.75a
Clethodim	2	0.00a	20.00ab	30.00b	52.5b	42.50b	62.50b
Potassium salt of Glyphosate	2	22.50a	57.50a	99.25a	90.00a	92.25a	94.50a
Sethoxydim	2	22.50a	52.50a	77.50a	92.00a	87.00a	96.75

Table 7. Efficacy control data of wheat (*Triticum aestivum* L.) per chemical treatment in the McGregor Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 7 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

McGregor Texas 2013		**Wheat Control**[b]					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00b	0.00c	0.00b	0.00b	2.5b	2.50b
Trifluralin	0[c]	42.50a	75.00a	80.00a	77.25a	77.25a	79.75a
1,2,4- Trimethylbenzene	2	0.00b	0.00c	2.50c	0.00b	2.5b	15.00b
Pendimenthalin	2	5.00b	15.00bc	15.00bc	2.50b	7.5b	7.50b
Carfentrazone-ethyl	2	2.50b	0.00c	0.00c	0.00b	0.00b	0.00b
Quizalofop P-ethyl	2	25.00ab	67.50a	70.00a	82.25a	77.5a	82.50a
Clethodim	2	5.00b	10.00bc	5.00c	2.5b	5.00b	17.50b
Potassium salt of Glyphosate	2	27.5ab	75.00a	77.50a	77.5a	85.00a	82.50a
Sethoxydim	2	20.00ab	50.00ab	57.50ab	57.25a	55.00a	70.00a

Clethodim, Sethoxydim, and Quizalofop P-ethyl ("Dim and Fop" Group) have the same mode of action in which the chemicals prevent fatty acid production in the chloroplasts by inhibiting Acetyl-CoA carboxylase activity (Burton et al., 1987). These chemicals were found to have a significant ($P \leq .05$) control impact on wheat during some of the rating periods in McGregor Texas and also in College Station Texas; though the control was delayed (**Tables 4-7)**. This is because Clethodim, Quizalofop P-ethyl, and Sethoxydim take two to three weeks before causing total mortality with Quizalofop P-ethyl often occurring sooner due to its ethyl formulation which aids in the herbicide uptake and transport into the cell (Naylor, 2008).

Potassium salt of Glyphosate is the chemical component found in various glyphosate products. This chemical is often used as a broad spectrum, non-selective herbicide because of its effectiveness in genetically modified glyphosate tolerant crops (de Maria 2006). Glyphosate inhibits specifically the enzyme EPSPS, which in turn reduces the biosynthesis of aromatic amino acids (Becerril et al., 1989). Between sites and both years potassium salt of glyphosate was found to be highly effective in volunteer wheat control ($P \leq 0.5$) in comparison to the untreated check plots. It was also found to be effective through more of the ratings dates than most other chemicals ($P \leq 0.5$) (**Tables 4-7)**.

Carfentrazone-ethyl is an herbicide in the phenyl triazolinone group often used as a broadleaf weed management herbicide (Baghestani et al., 2007). The chemical works through inhibition of protoporphyronogen oxidase (Protox) which is involved in the light-dependent formation of singlet oxygen responsible for membrane peroxidation

(Dayan et al., 1997) and was applied in the wheat sub-plot of the trial in order to keep all herbicide applications at a constant rate throughout the entire main plot. Photobleaching and necrosis is a common foliar injury to non-target crops with use of this herbicide but is usually overcome (Dayan et al., 1997). It has been determined that after absorption the chemical will become metabolized by the plant and becomes less potent (Dayan et al., 1997). This would be a potential explanation for the findings found in **Tables 5-7)** in which control was noted at an early rating of wheat but was no longer evident in later ratings; though there was an outlier that suggests the response was permanent (**Table 4**).

Though Pendimenthalin is found in the same chemical group as Trifluralin, response was not equal. Pendimenthalin is a pre-emergence herbicide and upon implementation in these trials the chemical was applied post-emergence, as based on the label for selected weed, which potentially reduced its effectiveness as a control for wheat. Evidence of its potential control can be found in **Table 7**. The emergence of crops at this location was delayed due to planting depth. Not all emergences had occurred upon application at the two leaf stage of the canola crop allowing for Pendimenthalin to have some effects as seen in the means in **Table 7**. Unlike Trifluraline, Pendimenthalin has low volatility and low water solubility, allowing it to remain viable for longer periods of time at the soil surface (Bandyopadhyay and Choudhury, 2009). This partial control with Pendimenthalin is not statistically significant but should be noted for future applications.

1,2,4-Trimethylbenzene was found to have no statistical difference compared to the untreated control regarding volunteer wheat management.

Mustard Control

Control of mustard was highly evident most rapidly when the chemical Carfentrazone-ethyl was applied. Within seven days after application mortality ranged from 88.75 to 99% (**Tables 8-11**). This is supported in other studies in which high mortality was found in broadleaf weeds within seven days after application (Durgan et al., 1997). The application of Carfentrazone-ethyl has also been found to be effective in relation to combinations of the chemical and various adjuvants therefore increasing its potential for use in weed control (Durgan et al., 1997). The chemical was found to be highly effective up to 70 days after treatment (**Tables 8-11**).

The only other chemical to demonstrate high significance in relation to untreated check plots was glyphosate ($P \leq 0.05$). Glyphosate was significantly different from the control starting at 14 to 21 DAA in all trials (**Tables 8-11**). The effectiveness of this chemical can be attributed to its broad spectrum of control. Previous studies have found that glyphosate chemicals are highly effective with control ranging from >95% of total biomass of various mustard species (Blackshaw and Harker, 2002).

The chemical Pendimethalin has been previously studied and findings suggest that the chemical is a viable option for oilseed control (Naylor, 2008). Therefore the responses found in College Station trials (**Tables 8, 10 and 11)** are evidence of potential but not supported by statistical significance. No other chemicals were found to have significant mustard control in relation to the untreated control.

Table 8. Efficacy control data of mustard (*Brassica Juncea* L.) per chemical treatment in the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2012. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

College Station Texas 2012		**Mustard Control**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00b	0.00c	5.00b	15.00c	15.00bc	12.50cd
Trifluralin	0	0.00b	0.00c	0.00b	0.00c	0.00c	0.00d
1,2,4- Trimethylbenzene	2	0.00b	0.00c	0.00b	0.00c	0.00c	2.50c
Pendimenthalin	2	0.00b	0.00c	17.50b	52.50b	60.00b	72.50abc
Carfentrazone-ethyl	2	88.75a	100.00a	75.00a	100.00a	100.00a	99.75a
Quizalofop P-ethyl	2	2.50b	0.00c	0.00b	0.00c	10.00c	25.00bcd
Clethodim	2	0.00b	0.00c	0.00b	0.00c	0.00c	0.00d
Potassium salt of Glyphosate	2	2.50b	67.50b	45.00ab	100.00a	75.00a	75.00ab
Sethoxydim	2	0.00b	0.00c	0.00b	0.00c	0.00c	0.00d

Table 9. Efficacy control data of mustard (*Brassica Juncea* L.) per chemical treatment in the McGregor Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2012. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

McGregor Texas 2012		**Mustard Control**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00b	0.00c	0.00a	0.00c	0.00c	0.00c
Trifluralin	0	0.00b	0.00c	25.00a	0.00c	0.00c	0.00c
1,2,4- Trimethylbenzene	2	15.00b	0.00c	0.00a	57.50b	52.50b	52.50b
Pendimenthalin	2	2.50b	0.00c	0.00a	0.00c	0.00c	0.00c
Carfentrazone-ethyl	2	90a	100.00a	49.75a	100.00a	100.00a	100.00a
Quizalofop P-ethyl	2	5.00b	0.00c	22.50a	0.00c	0.00c	0.00c
Clethodim	2	0.00b	0.00c	24.75a	0.00c	0.00c	0.00c
Potassium salt of Glyphosate	2	2.50b	20.00b	40.00a	96.75a	94.5a	94.50a
Sethoxydim	2	20.00b	0.00c	0.00a	5.00a	0.00c	0.00c

Table 10. Efficacy control data of mustard (*Brassica Juncea* L.) per chemical treatment in the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 7 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

College Station Texas 2013		**Mustard Control**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00b	0.00b	0.00b	0.00b	2.50b	0.00b
Trifluralin	0	10.00b	17.50b	24.75ab	24.75b	22.50b	27.50ab
1,2,4- Trimethylbenzene	2	17.50b	27.50b	35.00ab	7.50b	7.50b	17.50b
Pendimenthalin	2	30.00b	42.50ab	60.00ab	5.00b	40.00ab	25.00b
Carfentrazone-ethyl	2	97.25a	97.25a	100.00a	100.00a	100.00a	100.00a
Quizalofop P-ethyl	2	5.00b	2.50b	2.50b	20.00b	2.50b	27.50ab
Clethodim	2	0.00b	0.00b	0.00b	0.00b	0.00b	5.00b
Potassium salt of Glyphosate	2	12.50b	27.50b	57.50ab	62.5ab	64.74ab	69.75ab
Sethoxydim	2	15.00b	22.50b	22.50ab	22.5b	25.00b	22.50b

Table 11. Efficacy control data of mustard (*Brassica Juncea* L.) per chemical treatment in the McGregor Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 7 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

McGregor Texas 2013		**Mustard Control**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		2.50c	22.50b	0.00b	0.00b	0.00b	0.00b
Trifluralin	0	12.50c	5.00b	5.00b	0.00b	2.50b	5.00b
1,2,4- Trimethylbenzene	2	0.00c	0.00b	0.00b	0.00b	0.00b	0.00b
Pendimenthalin	2	2.50c	7.50b	17.50b	7.50b	5.00b	2.50b
Carfentrazone-ethyl	2	99.00a	100.00a	100.00a	100.00a	100.00a	100.00a
Quizalofop P-ethyl	2	15.00c	20.00b	20.00b	20.00b	17.5b	15.00b
Clethodim	2	0.00c	5.00b	0.00b	2.50b	7.50b	10.00b
Potassium salt of Glyphosate	2	64.75ab	87.25a	96.75a	72.5a	90.00a	90.00a
Sethoxydim	2	27.50bc	2.50b	7.50b	17.5b	20.00b	15.00b

Ryegrass Control

For reference, the incorporation date of Trifluralin was different in 2012 (14 days pre-plant) and 2013 (7 days pre-plant) allowing for less chemical degradation in 2013 as previously mentioned in wheat control results. A second point that should be noted is that ryegrass was sown into the soil in 2013 rather than broadcast by hand as was done in 2012. Originally the ryegrass was to be broadcast by hand within the 1.5 m x 1.5 m sub plots. After poor germination results and its effect on density variation between plots, which was highly evident in College Station Texas 2012, the following year (2013) ryegrass was sown into the soil. The results were an overwhelming improvement in germination rates and overall ryegrass density per plot. Due to this issue in germination rate and its effect on visual rating error data that was collected for 2012 was not incorporated into the results section. Mode of action information has been covered in previous sub sections therefor findings will be the only subject discussed in this section. Trifluralin was found to be rapidly effective at all sites in regards to means and highly significant ($P \leq 0.05$) in 2013 for both sites (**Tables 12 and 13**). Roughly 70% control of ryegrass was evident 7 DAA. The control persisted through to 70 DAA and reached 99.25%.

Table 12. Efficacy control data of ryegrass (*Lolium Perenne* L.) per chemical treatment in the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale. The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 7 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

College Station Texas 2013		**Ryegrass Control**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00b	2.50b	5.00b	0.00c	30.00cd	30.00cd
Trifluralin	0	74.75a	89.75a	99.50a	99.50a	99.00a	99.25a
1,2,4- Trimethylbenzene	2	0.00b	2.50b	0.00b	52.50b	52.50bc	57.50bc
Pendimenthalin	2	0.00b	0.00b	0.00b	0.00c	0.00d	0.00d
Carfentrazone-ethyl	2	10.00ab	5.00b	0.00b	0.00c	0.00d	0.00d
Quizalofop P-ethyl	2	25.00ab	50.00ab	99.25a	94.50a	99.00a	94.25ab
Clethodim	2	17.50ab	45.00ab	99.00a	92.00a	91.75ab	89.25ab
Potassium salt of Glyphosate	2	34.75ab	57.25a	97.00a	92.25a	92.25ab	96.75ab
Sethoxydim	2	49.75ab	60.00a	97.00a	99.25a	99.25a	99.00a

Table 13. Efficacy control data of ryegrass (*Lolium Perenne* L.) per chemical treatment in the McGregor Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale. The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 7 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

McGregor Texas 2013		**Ryegrass Control**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00b	7.50c	0.00c	2.50b	5.00c	5.00c
Trifluralin	0	70.00a	92.00a	92.00a	92.00a	94.25a	92.00a
1,2,4- Trimethylbenzene	2	0.00b	12.50bc	5.00c	17.50b	22.50bc	35.00bc
Pendimenthalin	2	12.50b	27.50bc	20.00bc	22.50b	22.50bc	22.50bc
Carfentrazone-ethyl	2	2.50b	0.00c	0.00c	0.00b	0.00c	0.00c
Quizalofop P-ethyl	2	30.00ab	87.50a	91.75a	94.75a	92.25a	92.25a
Clethodim	2	20.00ab	57.50ab	60.00ab	72.50a	62.50ab	60.00abc
Potassium salt of Glyphosate	2	37.5ab	87.25a	92.00a	92.25a	87.25a	87.50a
Sethoxydim	2	64.75a	96.75a	89.50a	92.00a	94.25a	89.50a

The “Dim and Fop” chemical group were all found to be statistically significant in 2013 between sites 14 DAA (**Tables 12 and 13**). The effects were rapid and consistent through 70 DAA.

Glyphosate was also a chemical found to have a positive response in ryegrass control. The chemical was evident with significance in relation to untreated control plots 21 DAA (**Tables 12 and 13**). Its mean control range was from 92 to 96.75% from 21 to 70 DAA.

Phytotoxicity

For the phytotoxicity component there are almost no effects caused by monocot herbicides in regards to means, and only two herbicides that are found to have statistical significance.

Studies have found that pendamethalin though often used *in B. napus* crops also shows high signs of phytotoxicity in areas of greater moisture (Chopra et al., 2010). The occurrence of phytotoxicity can be explained by the chemical leaching into the rooting zone *of B. napus* crops. The College Station Texas experiment site was managed for constant moisture to reduce plant stress and derive conclusions on moisture effects on herbicide activity. Precipitation at the College Station trial site was 544 mm in 2012 and 444 mm in 2013 while the McGregor Texas site had 482 mm in 2012 and 342 mm in 2013 potentially producing the phytotoxicity evident. Pendimenthalin shows little to no effect between 7 to 14 DAA across all sites and years. (**Tables 14-17)** At 21 DAA (2013) and 35 DAA (2012) it becomes evident that there is a significant ($P \leq 0.05$) residual effect occurring at the College Station site (**Tables 14 and 16**).

Table 14. Phytotoxicity data of canola (*Brassica napus* L.) per chemical treatment in the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2012. Phytotoxicity was rated on the basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

College Station Texas 2012		**Phytotoxicity**					
Chemical	**Application Timing Canola Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		2.50b	0.00b	0.00a	0.00b	0.00c	0.00c
Trifluralin	0	0.00b	0.00b	0.00a	0.00b	0.00c	0.00c
1,2,4- Trimethylbenzene	2	0.00b	0.00b	0.00a	0.00b	0.00c	0.00c
Pendimenthalin	2	0.00b	0.00b	22.50a	69.75a	87.50b	92.25b
Carfentrazone-ethyl	2	67.25a	75.00a	50.00a	75.00a	99.75a	100.00a
Quizalofop P-ethyl	2	5.00b	0.00b	0.00a	0.00b	0.00c	0.00c
Clethodim	2	0.00b	0.00b	0.00a	0.00b	0.00c	0.00c
Potassium salt of Glyphosate	2	10.00b	0.00b	0.00a	0.00b	0.00c	0.00c
Sethoxydim	2	2.50b	0.00b	0.00a	0.00b	0.00c	0.00c

Table 15. Phytotoxicity data of canola (*Brassica napus* L.) per chemical treatment in the McGregor Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2012. Phytotoxicity was rated on the basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale. The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

McGregor Texas 2012		**Phytotoxicity**					
Chemical	**Application Timing *B. napus* Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00c	0.00b	0.00a	0.00c	0.00b	0.00b
Trifluralin	0	5.00bc	0.00b	25.00a	0.00c	0.00b	0.00b
1,2,4- Trimethylbenzene	2	0.00c	0.00b	0.00a	0.00c	0.00b	90.00a
Pendimenthalin	2	5.00bc	0.00b	0.00a	5.00c	10.00b	0.00b
Carfentrazone-ethyl	2	82.50a	94.5a	49.75a	100.00a	99.25a	99.25a
Quizalofop P-ethyl	2	22.50b	0.00b	0.00a	0.00c	7.5b	7.50b
Clethodim	2	2.50bc	0.00b	25.00a	0.00c	0.00b	0.00b
Potassium salt of Glyphosate	2	2.50bc	0.00b	0.00a	0.00c	0.00b	0.00b
Sethoxydim	2	12.50bc	0.00b	0.00a	0.00c	0.00b	7.50b

Table 16. Phytotoxicity data of canola (*Brassica napus* L.) per chemical treatment in the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Phytotoxicity was rated on the basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale. The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

College Station Texas 2013		**Phytotoxicity**					
Chemical	**Application Timing *B. napus* Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		2.50b	2.50b	2.50c	0.00b	0.00b	2.50b
Trifluralin	0	5.00b	5.00b	10.00bc	0.00b	0.00b	0.00b
1,2,4- Trimethylbenzene	2	2.50b	10.00b	17.50bc	0.00b	0.00c	0.00b
Pendimenthalin	2	15.00b	27.50b	57.50ab	2.50b	27.50b	17.50b
Carfentrazone-ethyl	2	97.25a	97.25a	100.00a	100.00a	100.00a	100.00a
Quizalofop P-ethyl	2	5.00b	10.00b	7.50bc	0.00b	0.00b	0.00b
Clethodim	2	750b	5.00b	5.00bc	0.00b	0.00b	2.50b
Potassium salt of Glyphosate	2	10.00b	7.50b	20.00bc	2.50b	2.50b	0.00b
Sethoxydim	2	12.50b	12.50b	22.50bc	7.50b	15.00b	12.50b

Table 17. Phytotoxicity data of canola (*Brassica napus* L.) per chemical treatment in the McGregor Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site for 2013. Phytotoxicity was rated on the basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale. The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Trifluralin applied 14 days prior to planting. Abbreviations: lf, Leaf; DAA, Days After Application.

McGregor Texas 2013		**Phytotoxicity**					
Chemical	**Application Timing *B. napus* Stage, lf**	**7 DAA**	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00b	0.00b	0.00b	0.00b	0.00b	0.00b
Trifluralin	0	0.00b	o0.00b	0.00b	0.00b	0.00b	0.00b
1,2,4- Trimethylbenzene	2	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b
Pendimenthalin	2	0.00b	2.50b	2.50b	2.50b	0.00b	0.00b
Carfentrazone-ethyl	2	99.00a	100.00a	100.00a	100.00a	99.25a	99.25a
Quizalofop P-ethyl	2	2.50b	2.50b	12.50b	15.00b	12.50b	7.50b
Clethodim	2	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b
Potassium salt of Glyphosate	2	2.50b	17.50b	27.50b	15.00b	7.50b	2.50b
Sethoxydim	2	7.50b	15.00b	10.00b	10.00b	0.00b	0.00b

Carfentrazone-ethyl is the only other chemical that shows significant phytotoxicity in relation to the untreated check plots. This is due to the fact that Carfentrazone–ethyl is a broadleaf herbicide of which the *B. napus* has no resistance and caused nearly 100% mortality in all replicates of this treatment (**Tables 14, 15, 16, 17**).

Yield Results

Vernalization is a key component of winter *B. napus* yield production. Without the proper cold units and photoperiod, the crop can have a high reduction in total yield or potentially not go reproductive during the growing season (Saito and Saito, 2003). Interruption of cold periods can also reduce the onset of flowering and impact total yield (Saito and Saito, 2003). By interrupting the cold period necessary for vernalization by as much as 8°C, the plant can have diminished yield of up to 50% (Saito and Saito, 2003). During the growing season of 2012 the necessary cold units were not met at the College Station Texas site. This in effect caused a lack of yield for the first harvesting season of the trial and yield analysis was not possible.

The McGregor Texas field site was productive and yield was attained for this location. The results suggest that total yield, a surrogate to phytotoxicity when compared to control plots, was not significantly different ($P \leq 0.05$) in chemical applications except for two chemicals, 1,2,4, Trimethylbenzene and Carfentrazone-ethyl **(Table 18**). Referencing the phytotoxicity data one could infer that differences in Carfentrazone-ethyl yield were expected. The point of interest is that at McGregor, Texas in 2012, 1,2,4-Trimethylbenzene had zero visual phytotoxic effects yet yield data would suggest that phytotoxicity did occur.

Table 18. Mean yields for canola (*Brassica napus* L.) in three of the four growing periods for the Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial. College Station Texas 2012 site did not make yield therefor no data is shown. The mean yield is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05.

Chemical	Canola Yield (kg ha^{-1})		
	2012 Mcgregor	**2013 College Station**	**2013 McGregor**
Untreated Check	225.12a	868.68ab	102.20a
Trifluralin	196.72a	368.43abc	54.13a
1,2,4- Trimethylbenzene	21.97b	354.65abc	45.78a
Pendimenthalin	193.65a	835.70ab	74.58a
Carfentrazone-ethyl	0b	0.00c	0.00a
Quizalofop P-ethyl	228.92a	966.73a	36.10a
Clethodim	219.15a	305.98bc	97.53a
Potassium salt of Glyphosate	170.47a	783.18ab	84.88a
Sethoxydim	194.14a	220.08bc	111.98a

Discussion

The objective of the canola weed management experiment was to determine the most suitable herbicide(s) for weed control in canola in central Texas and by extension the southern Great Plains and include measures of their phytotoxicity and the effect on yield. The primary research questions were: 1) Which of eight herbicides would be the most effective to control weeds in a Glyphosate resistant canola cropping system? 2) Which of eight herbicides will produce the lowest phytotoxicity?

We found that Glyphosate was the only chemical that demonstrated control of all volunteer/weed species while maintaining a low to negligible phytotoxic effect. With this result, we could then accept our hypothesis, being that for this experimental trial glyphosate would be the best chemical for volunteer/weed control in a Glyphosate resistant *B. napus* cropping system.

CHAPTER IV

CONTROL OF BRASSICA NAPUS L. AS A VOLUNTEER/WEED

Synopsis

For this experimental trial there were two primary research questions to be answered. The first was which of ten herbicides is the most effective to control volunteer/weed Glyphosate resistant canola in a wheat cropping system? The second was which of the ten herbicides will produce the lowest phytotoxicity (greatest yield)? The objective of our second experimental trial was the determination of weed/volunteer control through herbicide efficacy testing of a Glyphosate resistant canola within a wheat cropping system. We hypothesized that Dimethylamine salt would be the most effective chemical for control of volunteer/weed Glyphosate resistant canola in a wheat cropping system because of its previous use history as a broadleaf herbicide. We also hypothesized that Dimethylamine salt would have the lease phytotoxic effect based on is current use in wheat cropping systems. Through a randomized complete block design study we discovered that Dimethylamine salt was a potential control for Glyphosate resistant canola though it was not the most efficient. We found that the chemicals Flufenacet and Bromoxynil had a greater control of volunteer/weed pressure while also demonstrating low phytotoxicity.

Introduction

With seed harvest losses ranging from 1% to 30% of the crop, a field can be consumed in volunteer populations of *B. napus* over time (Beckie et al., 2003; Lutman, 1993; Thomas et al., 1991). Even with newer harvesting practices and methods such as desiccation and swathing, *B. napus* seed has been found to be released into the soils at a rate of 10,000 seeds m^{-2} (Légère, 2005). In Canada, *B. napus* is found to be the 10^{th} most common weed in spring wheat and had 15% of the residual populations in many of the fields surveyed (Légère, 2005). With this production of volunteer *B. napus*, an extensive seed bank is created through seed dormancy and cyclical dormancy behavior that are influenced by factors such as environment, soil properties, and burial depth (Beckie et al., 2003). Seed can maintain viable for at least 5 years, and some volunteers have been observed for a maximum of 10 years (Beckie et al., 2003). Not only does this crop become a weedy problem for many years post-harvest, but volunteer canola can then become an issue in that it has a high potential to become a pollen source for weedy relatives in the surrounding areas (Beckie et al., 2003). Ninety percent of harvested canola is of a modified variety that is either Glyphosate or Glufosinate resistant (Brown et al., 2008). Due to the potential outcrossing of herbicide-tolerant *B. napus* it is imperative that effective volunteer management strategies become available (Brown et al., 2008). Genetically modified canola has multiple benefits including financial savings through reduced weed pressure for other crops, and soil retention while also increasing revenue through improved yield in a rotational wheat canola cropping system (Brown et al., 2008), but if populations begin to cross, the economic benefits are reduced due to the necessity to incorporate new weed management techniques caused by the new tolerance in cross-bred weeds (Begg et al., 2006). These occurrences have already been recorded and studied with trials suggesting 13.6% frequency of hybridization in wild populations found in commercial fields (Warwick, 1991).

Materials

The trials were planted with Armour wheat (*Triticum aestivum* L.) in both 2012 and 2013 years as the primary crop due to its previous success in these areas in regards to yield production and DK 4410 Round Up Ready canola (*Brassica napus* L.) as the volunteer weed species for both years due to the glyphosate resistance of the variety. Volunteer varieties were planted at .91 kg ha^{-1}, while the crop was planted at 50 kg ha^{-1}. There were 10 herbicides used in the treatment and 1 control each was replicated 4 times. The herbicides used along with the licensed product name, supplier and supplier location are found in **Table 19**.

Table 19. Chemicals used in the Control of *Brassica napus* L. as a volunteer/weed trial, its licensed product name, product supplier and location of supplier.

Chemical	**Product**	**Product Supplier and Information**	
Dimethylamine salt	Agri Star® 2,4-D Amine 4	Albaugh, Inc.	Ankeny, IA
Bromoxynil Octanoate	Buctril® 4EC	Bayer CropScience	Research Triangle PK, NC
Diglycolamine salt	Agri Star® Dicamba HD	Albaugh, Inc.	Ankeny, IA
Flufenacet	Axiom® DF	Bayer CropScience	Research Triangle PK, NC
Thifensulforn Methyl	Affinity® BroadSpec	Dupont™	Wilmington, DE
Flucarbazone Sodium	Finesse®	Dupont™	Wilmington, DE
Triasulfuron	Amber®	Syngenta Crop Protection, LLC	Greensboro, NC
Bromoxynil	Huskie®	Bayer CropScience	Research Triangle PK, NC
Pyroxsulam	PowerFlex®	Dow AgroSciences LLC	Indianapolis, IN
Mesosulfuron-methyl	Osprey®	Bayer CropScience	Research Triangle PK, NC

Methods

Experimental Design

Treatments were applied in a randomized complete block design 20 m x 30 m field section. The plots are based on the ten herbicide treatments and one untreated check for a total of eleven plots which were replicated four times for a total of 44 plots. Each plot was 1.5 m x 6 m separated by a .25 m buffer between treatments and 1.5 m buffer between replicates. Each plot was planted in 10 rows with .18 m spacing between rows of wheat planted at 56 kg ha^{-1} and *B. napus* the weed volunteer/weed species planted on top of the wheat in 10 rows spaced at .18 m between rows at .91 kg ha^{-1}. Trials were provided Nitrogen fertilizer at a rate of 112 kg ha^{-1} at Feekes 4.

These trials were performed in two consecutive years (2011-2012 and 2012-2013) and were planted in mid-November (November 15 2011 and November 12 2012). The trials were planted in a the two study site location with the McGregor crops planted after a corn rotation and the College Station crops planted after a cotton rotation.

Herbicide Application

Herbicide application was completed across each plot and applied to all four replicates. The treatment consisted of the labeled application rate for each active ingredient per hectare (ai ha^{-1}) diluted in .175 liters of water (48.6 L ha^{-1}) (**Table 20).** Several treatments also included labeled surfactants (**Table 20)**. The herbicide was applied using a 1.5 m walking boom sprayer set at 55 psi with four standard flat fan nozzles at 0.25 m spacing. The boom was held at 0.25 m above soil surface and moved through the plot at a pace of 1.2 m s^{-1}.

Table 20. Chemicals applied to the Control of *Brassica napus* L. as a volunteer/weed trial including the specific rates and mix components per treatment. Abbreviations: kg, Kilograms; ai, active ingredient; ha, hectare. Non Ionic Surfactant rate applied as (V/V%). Ammonium Sulfate applied as (kg ha^{-1}). Urea Ammonium Nitrate applied as (mL ha^{-1})

Chemical	Rate
	kg ai ha^{-1}
Control	
Dimethylamine salt	0.80
Bromoxynil Octanoate	0.56
Diglycolamine salt	0.28
Flufenacet	0.48
Thifensulforn Methyl	0.04
Flucarbazone Sodium	0.03
Non Ionic Surfactant	0.50
Triasulfuron	0.02
Non Ionic Surfactant	0.50
Bromoxynil	0.26
Ammonium Sulfate	1.12
Pyroxsulam	0.02
Mesosulfuron-methyl	0.01
Non Ionic Surfactant	0.50
Urea Ammonium Nitrate	5.50

Efficacy Rating

Efficacy ratings were conducted using a visual rating method in which the observer measures the percent weed control in regards to mortality (complete necrosis or abscission) for each herbicide and its percent of phytotoxicity (Complete necrosis or abscission) to the crop (Vanhala et al., 2004). This is done by determining percent mortality in relation to an untreated check plot. The percent control and phytotoxicity will be measured using a scale of 0 – 10 where zero is equivalent to 0% percent mortality and 10 is equivalent to 100% mortality. This method increases the accuracy of rating systems, since the ability to determine a change of 1% is difficult for a researcher to determine. At 10% the researcher has the ability to stay within the bounds of variability.

These ratings were performed at various intervals set at 7 days after application (DAA), 14 DAA, 21 DAA, 35 DAA, 49 DAA, 70 DAA. **Table 3** lists the actual dates for these rating periods for both years.

Yield Analysis

The herbicide treatments may have an adverse effect on the wheat crop. Consequently, phytotoxicity level of all herbicides applied was also measured by harvesting crops in each plot to determine the seed yield. Seed yield was determined by weighing and the mean plot weight was compared between herbicide treatments.

Efficacy Rating Results

Results are presented as an interpretation across sites and years with relevant information as to mode of action and significance of control in relation to untreated checks.

Results

Glyphosate Resistant B. napus control

For reference, in 2013 two variables contributed to rapid mortality ratings in both College Station Texas and McGregor Texas. In College Station, Texas 3 days prior to rating day 21 DAA, insect pressure was noted. The insect was the *Diabrotica undecimpunctata* (Spotted cucumber beetle). Upon 21 DAA data collection, insect pressure had greatly reduced standing canola biomass. Lambda Cyhalothrin insecticide was applied two days after the 21 DAA rating. Weather did not permit for sooner application. At 35 DAA, the canola crop had been decimated by over 90% of the original standing crop. In McGregor Texas, moisture post-planting was not favorable for plant growth and along with deeper planting depth for moisture contact, delayed emergence occurred as well as poor germination in areas.

The most rapid chemical for volunteer *B. napus* control was Flufenacet with a significance of $P \leq 0.05$ in relation to untreated check plots. Mortality ranged from 55 to 99.75% across both sites and both years (**Tables 21-24)**. Flufenacet is a seedling root and shoot inhibitor. The chemical is often used for control of annual grasses but may also be used for broadleaf control. The primary site of absorption for broadleaf plants is found to occur most often in the roots (Peterson et al., 2001)

Table 21. Efficacy control data of canola (*Brassica napus* L.) per chemical treatment in the College Station Texas Control of *Brassica napus* L. as a volunteer/weed trial site for 2012. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Abbreviations: DAA, Days After Application.

College Station Texas 2012							
Chemical	**Application Timing Wheat Stage, FEEKES**	**Rating Periods**					
		7 DAA	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00d	0.00d	0.00d	0.00b	0.00b	0.00b
Dimethylamine salt	2	12.50cd	5.00cd	32.50bcd	100.00a	99.75a	100.00a
Bromoxynil Octanoate	2	45.00b	99.50a	99.50a	99.75a	100.00a	100.00a
Diglycolamine salt	2	2.50cd	25.00bcd	65.00abc	94.75a	100.00a	100.00a
Flufenacet	2	80.00a	72.00abc	97.00a	97.00a	95.00a	89.75a
Thifensulforn Methyl	2	0.00d	22.5bcd	45.00abcd	85.00a	97.50a	97.50a
Flucarbazone Sodium	2	0.00d	0.00d	67.50abc	100.00a	100.00a	100.00a
Triasulfuron	2	0.00d	0.00d	45.00abcd	95.00a	100.00a	100.00a
Bromoxynil	2	20.00c	74.50ab	74.50ab	74.75a	75.00a	75.00a
Pyroxsulam	2	0.00d	0.00d	12.50cd	72.75a	90.00a	100.00a
Mesosulfuron-methyl	2	0.00b	0.00b	25.00bcd	79.75a	100.00a	99.75

Table 22. Efficacy control data of canola (*Brassica napus* L.) per chemical treatment in the McGregor Texas Control of *Brassica napus* L. as a volunteer/weed trial site for 2012. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Abbreviations: DAA, Days After Application.

McGregor Texas 2012							
Chemical	**Application Timing Wheat Stage, FEEKES**	**Rating Periods**					
		7 DAA	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		0.00c	0.00b	2.50c	17.50b	2.50c	7.50c
Dimethylamine salt	2	7.50b	0.00b	32.50bc	65.50ab	99.75a	100.00a
Bromoxynil Octanoate	2	67.50b	95.75a	99.50a	100.00a	100.00a	100.00a
Diglycolamine salt	2	0.00c	2.50b	42.50bc	75.00ab	100.00a	100.00a
Flufenacet	2	99.75a	100.00a	100.00a	100.00a	100.00a	100.00a
Thifensulforn Methyl	2	0.00c	0.00b	42.50bc	100.00a	100.00a	100.00a
Flucarbazone Sodium	2	0.00c	2.50b	67.50ab	100.00a	100.00a	100.00a
Triasulfuron	2	0.00c	0.00b	45.00bc	100.00a	100.00a	100.00a
Bromoxynil	2	62.50b	96.75a	94.50a	100.00a	100.00a	100.00a
Pyroxsulam	2	0.00c	0.00b	12.50bc	45.00ab	85.00a	89.75a
Mesosulfuron-methyl	2	0.00c	0.00b	25.00bc	52.50ab	100.00a	100.00a

Table 23. Efficacy control data of canola (*Brassica napus* L.) per chemical treatment in the College Station Texas Control of *Brassica napus* L. as a volunteer/weed trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Abbreviations: DAA, Days After Application.

College Station Texas 2013							
Chemical	**Application Timing Wheat Stage, FEEKES**	**Rating Periods**					
		7 DAA	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		2.50d	35.00b	44.75b	60.00b	62.50b	67.50a
Dimethylamine salt	2	45.00abcd	65.00ab	100.00a	100.00a	100.00a	85.00a
Bromoxynil Octanoate	2	75.00ab	87.25a	100.00a	100.00a	100.00a	100.00a
Diglycolamine salt	2	10.00cd	50.00ab	82.25ab	100.00a	100.00a	100.00a
Flufenacet	2	60.00abc	72.50ab	100.00a	100.00a	100.00a	100.00a
Thifensulforn Methyl	2	55.00abcd	60.00ab	100.00a	100.00a	100.00a	100.00a
Flucarbazone Sodium	2	10.00cd	62.50ab	99.75a	100.00a	100.00a	100.00a
Triasulfuron	2	10.00cd	60.00ab	100.00a	100.00a	100.00a	100.00a
Bromoxynil	2	77.50a	87.25a	100.00a	100.00a	100.00a	100.00a
Pyroxsulam	2	32.50abcd	57.50ab	99.75a	100.00a	100.00a	100.00a
Mesosulfuron-methyl	2	22.50bcd	60.00ab	100.00a	100.00a	100.00a	100.00a

Table 24. Efficacy control data of canola (*Brassica napus* L.) per chemical treatment in the McGregor Texas Control of *Brassica napus* L. as a volunteer/weed trial site for 2013. Efficacy rated on basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05. Abbreviations: DAA, Days After Application.

McGregor Texas 2013							
Chemical	**Application Timing Wheat Stage, FEEKES**	**Rating Periods**					
		7 DAA	**14 DAA**	**21 DAA**	**35 DAA**	**49 DAA**	**70 DAA**
Untreated Check		2.50c	47.50ab	45.00a	47.50b	57.50a	55.00a
Dimethylamine salt	2	15.00c	97.50ab	99.75a	100.00a	100.00a	100.00a
Bromoxynil Octanoate	2	80.00a	100.00a	100.00a	100.00a	100.00a	100.00a
Diglycolamine salt	2	17.50c	55.00ab	52.50a	90.00ab	75.00a	75.00a
Flufenacet	2	52.50b	100.00a	95.00a	99.75a	100.00a	100.00a
Thifensulforn Methyl	2	12.50c	100.00a	100.00a	100.00a	100.00a	100.00a
Flucarbazone Sodium	2	25.00c	100.00a	100.00a	100.00a	100.00a	100.00a
Triasulfuron	2	15.00c	100.00a	100.00a	100.00a	100.00a	100.00a
Bromoxynil	2	80.00a	100.00a	100.00a	100.00a	100.00a	100.00a
Pyroxsulam	2	7.50c	100.00a	100.00a	100.00a	100.00a	100.00a
Mesosulfuron-methyl	2	5.00c	97.50a	100.00a	100.00a	100.00a	100.00a

The Bromoxynil chemical group followed in regards to rapid canola control ranging from 20 to 80% 7DAA in both sites across both years (**Tables 21-24)**. Two Bromoxynil chemical constructs were incorporated into the experiment and the mode of action for these chemicals was the same. The Bromoxynil group works through inhibition of the electron transport in photosystem II (AYRES, 1982). Bromoxynil is a widely used broadleaf herbicide that takes effect within a few hours most times with delayed responses occasionally reaching 1-2 weeks (Naylor, 2008). In our experiments, the responses were rapid in that significant differences ($P \leq 0.05$) were seen 7 DAA. It should be noted that Bromoxynil was applied at a lesser concentration rate of active ingredient than the Bromoxynil Octanoate (**Table 20**). Although the chemical application was more than half the Bromoxynil Octanoate compound the responses were relatively similar with both having rapid responses and high early mortality.

In 2012, mortality levels were relative between sites and high mortality rates were reached at 21 DAA for most all chemicals (**Table 21 and 22)**. Only Dimethylamine salt, Thifensulfuron Methyl and Pyroxsulam had slower responses when related to all other chemicals. This was evident at both locations in 2012 (**Table 21 and 22**). Dimethylamine salt along with 2-ethylhexyl ester forms account for 90 – 95% of the total global use suggesting is effectiveness in weed control (Charles et al., 2001). The chemical works through over expression of cell division in the vascular tissue which cause abnormalities and in response mortality (Naylor, 2008). Both Thifensulfuron Methyl and Pyroxsulam are acetolactate synthase inhibitors. This inhibition reduces the production of end product branch chain amino acids which effect seedling growth showing varying signs of malformation, stunting, and reduced seed production (Whitcomb, 1999). An explanation for the less rapid response with use of these chemicals is that the observer did not consider abnormal growth as mortality in the rating system therefore the period in which final mortality occurred may have been longer than the first response to the chemicals. At 35 DAA, all herbicides had reached or were significantly close to maximum control (**Tables 21, 22, 23, 24**).

Phytotoxicity

At the College Station trial site in 2012 only Flufenacet showed signs of phytotoxicity with the greatest significance at 35 DAA and 49 DAA (**Table 25**). Though this was not recorded the following year nor in any year at the McGregor site.

Table 25. Phytotoxicity data of wheat (*Triticum aestivum* L.) per chemical treatment in the College Station Texas Control of *Brassica napus* L. as a volunteer/weed trial site for 2012. Phytotoxicity was rated on the basis of percent mortality from 0-100% with ratings done on a 10 scale (0 is equivalent to no mortality and 10 is equivalent to 100% mortality. Data shown here has been transformed to 100% scale**.** The mean control is shown followed by a letter. Each mean followed by the same letter identifies non-significant differences according to Fisher's Protected LSD at P≤0.05. DAA, Days After Application.

Chemical	**Application Timing Wheat Stage, FEEKES**	**Rating Periods**	
		35 DAA	**49 DAA**
Untreated Check		0.00b	0.00b
Dimethylamine salt	2	0.00b	2.50b
Bromoxynil Octanoate	2	2.50b	2.50b
Diglycolamine salt	2	10.00b	15.00ab
Flufenacet	2	40.00a	37.50a
Thifensulforn Methyl	2	10.00b	0.00b

Table 25. Continued.

Chemical	Application Timing Wheat Stage, FEEKES	Rating Periods	
		35 DAA	49 DAA
Flucarbazone Sodium	2	0.00b	17.50ab
Triasulfuron	2	0.00b	0.00b
Bromoxynil	2	0.00b	0.00b
Pyroxsulam	2	0.00b	0.00b
Mesosulfuron-methyl	2	0.00b	0.00b

Yield Analysis

At the College Station trial site in 2012, it was revealed that Thifensulfuron and Pyroxsulam had an improvement in yield that were significantly different ($P \leq 0.05$) than the untreated check but no significant differences to other applications were evident for this site and year (**Table 26**). This trend was evident at College Station in 2012, but was not evident in any of the three other location/years. In 2012 at the McGregor experimental site, there were no significant yield differences between treatments. This was also the case at the College Station site in 2013 **(Table 26**). In 2013 at the McGregor experimental site, it was determined that Diglycolamine salt had a reduction of yield in comparison to all other treatments and the untreated check plots. The trend in decreased mean yield was evident across years and sites, but could not be proven to be statistically significant at an alpha level of 0.05.

These results would suggest that there were no specific chemicals that had a significant reduction of yield. Therefor any of these chemicals would be a viable option for use with respect to yield. What would also be of interest is that based on relation to untreated checks, the variation in yield was not significantly different in most applications across years except for College Station 2012, suggesting that the volunteer canola did not have a major impact on yield. Though this was evident in our study, much work has been done to determine whether volunteer canola would have an adverse effect on wheat yields. Studies have shown that increased herbage of *Brassica* spp. would decrease seed yields in many cereal crops (Mayer and Furtan, 1999; Vera et al., 1987).

Table 26. Mean yields for wheat (*Triticum aestivum* L) for the Control of *Brassica napus* L. trial. The mean yield is shown followed by a letter. Each mean followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05.

	2012 Wheat Yield		**2013 Wheat Yield**	
Chemical	**College StationTX**	**McGregor TX**	**College StationTX**	**McGregor TX**
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Untreated Check	1408.97b[a]	3938.36a	3103.37a	3929.62abc
Dimethylamine salt	2943.17ab	3812.87a	3120.36a	3316.50bcd
Bromoxynil Octanoate	2692.25ab	3239.35a	3461.59a	3803.47abc
Diglycolamine salt	2577.59ab	3632.20a	2636.43a	3168.38d
Flufenacet	2401.52ab	3839.52a	3286.50a	3419.76bcd
Thifensulfuron Methyl	3072.25a	3818.19a	3314.20a	3874.16abc
Flucarbazone Sodium	2844.63ab	3472.04a	3698.13a	4095.91a
Triasulfuron	2937.10ab	3667.89a	3367.80a	3924.97ab
Bromoxynil	3018.24ab	3492.31a	3293.49a	3759.90abcd
Pyroxsulam	3165.40a	3612.30a	2930.42a	3791.29abcd
Mesosulfuron-methyl	2850.18ab	3034.51a	3816.61a	3924.97ab

Discussion

The objective of the volunteer/weed herbicide resistant canola experiment was to determine the most suitable herbicide(s) for canola control in a wheat cropping system in central Texas and include measures of their phytotoxicity and the effect on yield. The primary research questions were: 1) Which of ten herbicides is the most effective to control a Glyphosate resistant canola in a wheat cropping system? 2) Which of ten herbicides will produce the lowest phytotoxicity?

Although Dimethylamine salt had significant control of volunteer canola within a wheat cropping system, it was not the most effective herbicide for volunteer canola control in regards to rapid control and mean yield. This was based on efficacy results and yield results found in **Tables 21-25**. Chemicals such as Flufenacet and Bromoxynil would be recommended based these characteristics. With this result, we could then accept our hypothesis. The hypothesis for this experimental trial being that glyphosate would be the best chemical for volunteer/weed control in a Glyphosate resistant *B. napus* cropping system.

We hypothesized that Dimethylamine salt would be the most suitable herbicide in volunteer canola control and reduced phytotoxicity. We can neither accept nor reject this hypothesis on the basis that Dimethylamine salt was an effective herbicide in volunteer/weed canola control and low phytotoxic levels, but it was not significantly different than any other chemical compound either.

CHAPTER V

DISCRIMINATION AND MAPPING OF WEEDS/VOLUNTEERS AND CROPS USING TERRESTRIAL LASER SCANNING

Synopsis

The objective of this trial was to first determine if terrestrial laser scanning could be used as a precision agricultural tool to map distribution of weed presence in broadleaf and monocot cropping systems. If possible, the secondary objective was to quantify weed density in our first trial in which canola was a crop using Terrestrial Laser Scanning (TLS) technology as a precision farming tool. Relationships between structural point densities and there specific intensity values proved to be a significant measure of weed abundance. The tool was found to be a plausible measure for differentiation between weed species and the current crop through the distribution mapping of the weed pressure (weed density). This was evident in the accuracy assessments in which the tool was > 90% accurate when estimating species presence.

Introduction

In 1999, field studies began to use digital image analysis for automatic weed detection (Gerhards et al., 2012). Though this method is highly efficient, the technology does not allow for identification of weeds that grow in the crop's understory.

Terrestrial Laser Scanning (TLS) is a relatively new technology that has been developed for use in the industrial sector (Lemmens, 2011). This technology is a LiDAR (Light Detection-and-Ranging) ground system (Lemmens, 2011). The concept is that a laser light source is emitted from a sensor head and when that light source is intercepted by an object the light is reflected back to the sensor head where time-of flight is calculated and converted to distance traveled or range (Pesci and Teza, 2008). This measurement is taken in X, Y, and Z coordinates allowing for a three dimensional rendering of all points intercepted or what is referred to as a point cloud (Höfle and Pfeifer, 2007).

Previous studies demonstrated that TLS could be used to predict dry weights in crop systems, specifically wheat, using TLS derived plant area density correlations with manual measurements of dry weight (Hosoi and Omasa, 2009). Other works have also incorporated this technology into field trials for attaining wheat height measurements and grain yield estimates (Lumme et al., 2008). These particular trials demonstrated the potential for the incorporation of TLS in agricultural systems.

Not only does the system provide structural information in regards to point densities, each point is also given an intensity value (Lumme et al., 2008). The intensity value is the maximum reflectance at the TLS's wavelength from an object (Lemmens, 2011). This value is a function of the surface properties, particularly absorption, transmittance, and reflectance of the target, the distance between the laser and the target, the angle of incidence of the laser beam impinging on the target surface, the transmitted power of the laser, and the atmospheric attenuation coefficient of the air through which the beam has traveled (Kaasalainen et al., 2011; Kaasalainen et al., 2010; Wang and Lu, 2009). In general, all LiDARs measure range and intensity of intercepted points (Lemmens, 2011).

Eitel et al. (2010) have shown that the intensity values relate to the amount of foliar nitrogen and chlorophyll-a and b within a plant with correction for incidence angle. With correction for these variables, it is possible to attain the specific intensity value for each point that in turn could be used to discriminate between weedy plants and actual harvestable crops. To the best of our knowledge there have been no other attempts to use this technology for its potential use in the three-dimensional modeling of fields with the ability to both discriminate weeds from crops, and the calculation of their respective densities.

Materials

In this study a Leica ScanStation 2 (Leica-Geosystems, 2012) (**APPENDIX B**) TLS with > 0.5-mm X 0.5-mm adjustable scanned spacing through a customizable 360° horizontal and 270° vertical scan area of a 532 nm wavelength green laser with a pulse frequency of 55,000 points per second and a spot diameter of 4.5-mm. This TLS has a range accuracy of ± 2-mm

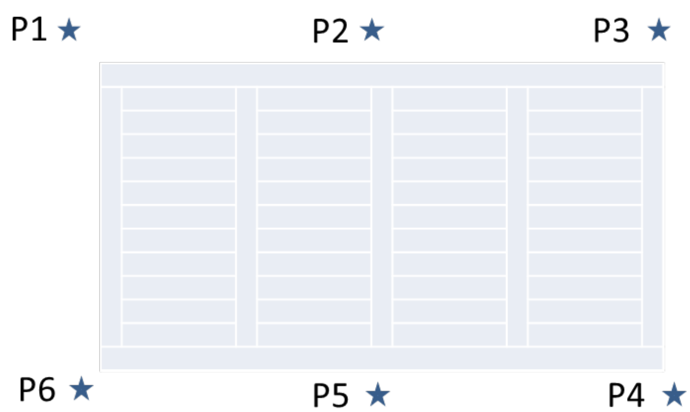
Methods

Pre Processing Methods

Data Acquisition

Six scans were positioned around the Weed/Volunteer Control in Glyphosate Resistant *Brassica napus* L. trial (**Figure 2**). These scans were done at the 6-9 leaf stage of the *B. napus* on January 14, 2013. These scans were acquired with the TLS at a height of 1.65 m for consistent vertical reflectance angles (Höfle and Pfeifer 2007) and a fixed posting or resolution of 2-cm X 2-cm. Multiple scans were required to reduce shadowing and to capture obscured objects due to line of site interference**.** Corner scans were performed at 90° angles and set at a scanning range of 80 m to span the distance of the both trials which is roughly 75 m from corner to corner of both trials. Boundary scans were performed at 180° angles and set a scanning range of 50 m. Three target poles were set at random throughout each trial as set positions for scan registration. Data acquisition was only performed in College Station Texas.

Figure 2. Illustration of scanning positions around the College Station Texas Weed/volunteer control in Glyphosate resistant *Brassica napus* L. trial site in Chapter 3.



Point Cloud Standardization

When the TLS captures data, its vertical elevation above the ground is the reference vertical datum. Consequently, below the plane of the TLS's height, elevation values are negative. To correct for this, a simple transformation function was applied to adjust the elevation height, in which the corrected information is the sum of the original elevation and the inverse minimum elevation. The original elevation is that returned by the scanning unit. The minimum elevation is derived using Surfer (Golden-Software, 2009)by querying the height (z value) data column for minimum extent.

Once height was adjusted the data was then filtered for vegetation only data. Soil points would be irrelevant in classification of vegetation and would potentially interfere in future grid sampling for mean derivation. To remove the soil, a conditional statement operation was applied in which if at any (X,Y) position the elevation was less than or equal to 0.05 m the data was true and transformed to zero elevation while if opposite, the response was false, and data was left as its original form. The data was then sorted based on elevation and all zero elevation data was removed.

To determine range effect on intensity the data had to be transformed to a known distance from scanning unit. This is because data is captured as Cartesian coordinates in reference to the scanning unit and from a given height (Lemmens, 2011). To attain actual distance the Euclidian distance formula was applied along with an elevation correction and the Pythagorean Theorem was solved to provide the actual distance of each point from scanning sensor.

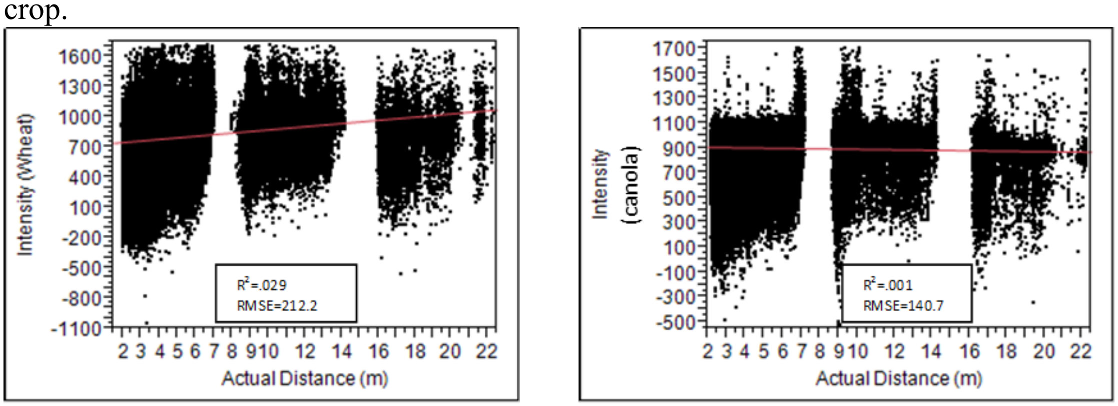
Post Processing Methods

Approach 1 - Intensity Discrimination

Approach 1 Viability Testing

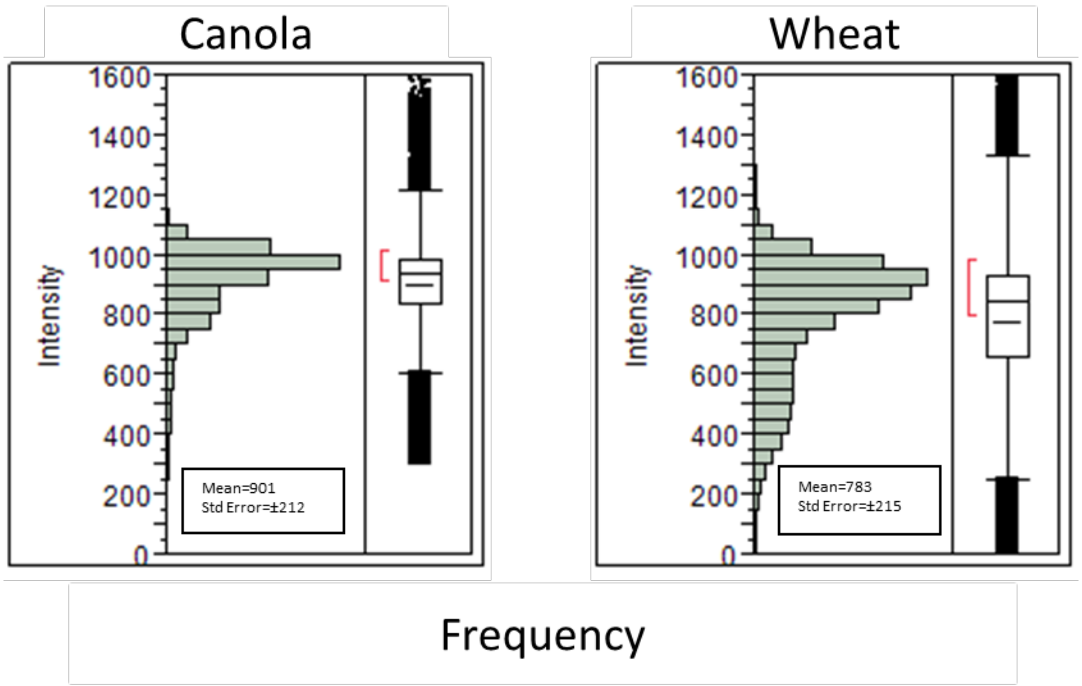
Figure 3 illustrates the bivariate fit of wheat intensity to distance and the bivariate fit of canola by distance. The results suggest that there is no significant intensity change for either species for the distance range from 1 m to 20 m which was found to be the same as the discoveries by Eitel et al. (2010) that suggested a near distances intensity values did not vary due to return signal loss. This information would suggest that at a range of 20 m there is no significant net effect of intensity loss or gain. What could also be interpreted is that angle of incidence did not have an effect on intensity either. Hofle and Pfeifer (2007) suggest that at a stationary height, angle of incidence is corrected linearly with distance assuming there is little to no variation of height in objects being measured. In this case crops were uniform stands of canola and wheat.

Figure 3. Bivariate fit of wheat intensity to distance and the bivariate fit of canola by distance with correlation and root mean standard error values provided. Figures suggest no significant change of intensity in relation to distance from scanning point for either crop.



After analysis of bivariate fit of both canola and wheat by actual distance it was evident that no corrections were necessary to adjust for loss or gain of intensity at the 1 m to 20 m range. Therefore the data was run in a frequency distribution model to derive mean intensity values for definition used in data filtering. **Figure 4** illustrates the distribution response of all data points classified as wheat and all data points classified as canola along with an outlier boxplot for context of data variation.

Figure 4. Distribution response of all data points classified as canola and all data points classified as wheat along with an outlier boxplot for context of data variation and means and standard error of means.



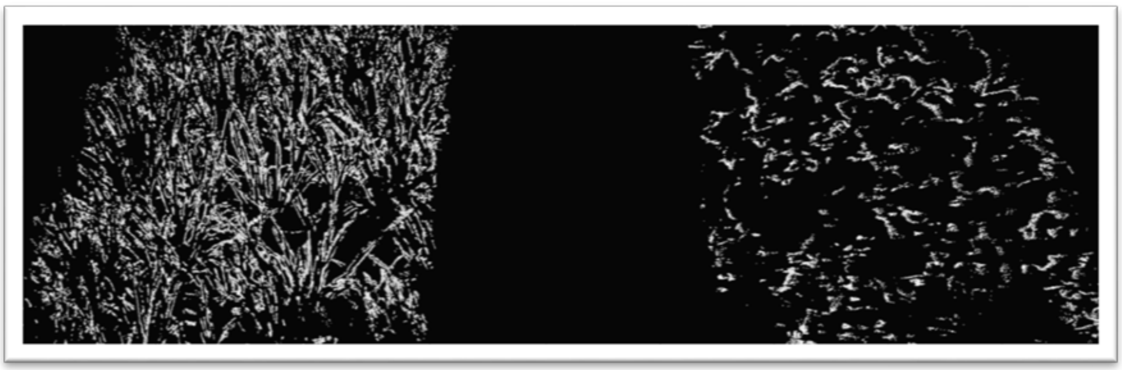
This information suggests that mean intensity between species was not significantly different and would not be a satisfactory method for definition filtering to segregate species types.

Approach 2 - Edge Effect Mapping

Approach 2 Viability Testing

In order to discriminate using edge effect point density a threshold limit had to be created for determining the mean point densities for each species monocot and dicot. This was done by first applying the point cloud standardization equations to the collected training data of a monocot and dicot crop. Filtering of the training data was then performed so as to only retain edge effect point data (**Figure 5**). The filtering process was done using Surfer by sorting the point data based on intensity value and deleting all values that did not fit the Eitel et al. (2010) edge effect value.

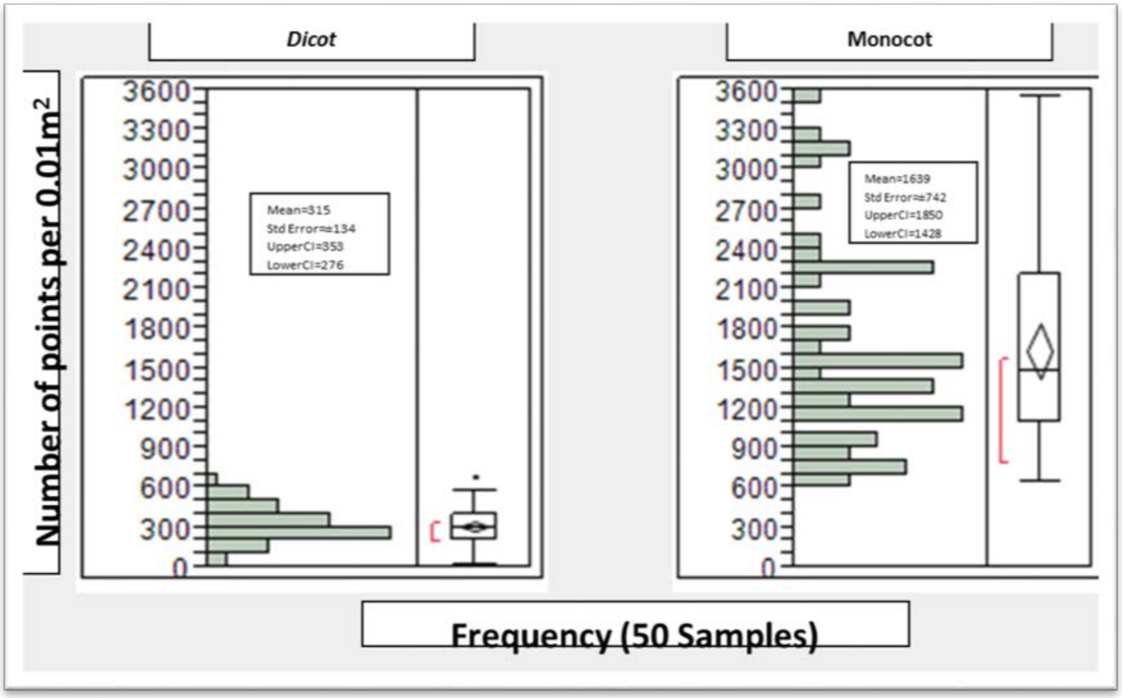
Figure 5. Illustration of intensity filtered data of a monocot and dicot species in which only edge effect intensity values remain.



Once filtered, sampling of 50 0.1 x 0.1 m cells of known canola presence areas and 50 0.1 x 0.1 m cells of known wheat areas were taken. The sampling was used to calculate the density of points in each cell. The densities for each cell were run in JMP (SAS-Institute-Inc., 2013) and analyzed as a frequency distribution. The upper 95% CI of canola was set as the threshold for dividing wheat and canola pixels.

The sub sample analysis of 50 0.1 x 0.1 m samples of canola and 50 0.1 x 0.1 m samples of wheat suggested no overlap between point densities (**Figure 6**). This allowed us to develop a threshold for classification in which all grid cells having a cell point density greater than 353 points would be classified as wheat or monocot species.

Figure 6. Frequency distribution graphs of dicot and monocot point density samples taken using a 0.01 m x 0.01 m virtual quadrat. Mean estimate of point density along with mean standard error and confidence intervals (alpha = 0.05) are provided within graphs.



Mapping

The next step after determining the thresholds of each crop was to separate specific trial data. Since this method only allows for discrimination based on monocot and dicot combinations, specific data had to be separated. The trial being used for analysis was the split plot design found in the Weed/Volunteer Control in Glyphosate Resistant *Brassica napus* L. trial. The split plot design incorporated a combination of canola and wheat in one subset and canola and ryegrass in a second subset both of which are monocot/dicot combinations. These point data sets would be used in the monocot dicot discrimination. To do the separation, Cyclone was used to crop the specific subsections in each trial using the cropping tool. This was done for each of the six scans. To remove overlapping data between scans the nearest eight subplots to the scanning position were then again cropped from each scan using the cyclone cropping tool. The scans were then corrected independently using the *Point Cloud Standardization* method as previously described. Once standardized, the data was then filtered for retention of only edge effect data. This again was done using Surfer sort and delete method based on the Eitel et al. (2010)definition. The data for each independent scan was then gridded using Quick Terrain Modeler (Applied-Imagery-LLC, 2013). The gridding was done using the Grid Statistics tool found in Quick Terrain Modeler (QTM) (Applied-Imagery-LLC, 2013) which will grid data at a user defined cell geometry and will attribute specific data as the cell value. For our purpose, we used a 0.1 m x 0.1 m grid cell geometry and an attribute of total point density within the cell. This grid cell spacing was used to increase the area of point density so that a better estimate of point density can be evaluated without issues that may arise from shadowing. The gridded data was then exported using to ArcGIS 10 (ESRI, 2013) where it was classified on a low to high value classification.

The subset data was mapped using the threshold constraints developed in the viability testing phase. The resulting map can be found in **APPENDIX B**. The map is an illustration of a subset plot of the Weed/Volunteer Control in Glyphosate Resistant *Brassica napus* L. trial which is mapped in the high to low weed density method.

Accuracy Assessment

Accuracy Assessment Methods

5 known wheat locations and 5 known canola locations were derived using the rendered point cloud image in which the user entered the 3-D image and located species Cartesians positions. Cartesian positions were entered as (X,Y) positions in ArcGIS 10 (ESRI, 2013). The points were then overlaid with the previously developed high low classification map. The point and the distribution map were then run as a spatial intersection and data was matched to determine the accuracy of the map. This was done for all subset plots in the Weed/Volunteer Control in Glyphosate Resistant *Brassica napus* L. trial of monocot dicot combinations (wheat:canola and ryegrass:canola).

Accuracy Assessment Results

The results suggested that this method was a viable application for discrimination of a monocot species in a dicot cropping system. This was also correct for the inverse in which discrimination of dicots were assessed by classifying in the same edge effect method but attributing the gridded spacing based on reduced edge effect density. The results of the accuracy assessment can be found in **Table 27**.

Table 27. Data represents each species classified as a monocot or dicot. Accuracy data are all points gathered by user as known species location. Correct attribute are total number of correct intersections between known and mapped points. Percent accuracy is the ratio of correct attributes to total number of known positions.

Classification	Accuracy Data	Correct Attribute	Percent Accuracy
B. napus	180	162	90%
Wheat	180	175	97%
Rye Grass	180	171	95%

Results and Discussion

The objective of this trial was to first determine if terrestrial laser scanning could be used as a precision agricultural tool to map distribution of weed presence in broadleaf and monocot cropping systems. If possible, the secondary objective was to quantify weed density in our first trial, Weed/Volunteer Control in Glyphosate Resistant *Brassica napus* L., using Terrestrial Laser Scanning (TLS) technology as a precision farming tool.

For this section we asked, can intensity values or a combination of intensity value and structure (Edge Effect) be used to discriminate between volunteer/weed species and crops? We hypothesized that through structure (Edge Effect) and intensity returns of a 532 nm wavelength laser, we would be able to differentiate between weed species and the current crop for distribution mapping of weed pressure (weed density). After analysis, we found that there are variations between monocots and dicots that can be used to discriminate between the two, though this was only found to be accurate when looking at the combination method of intensity and structure. These differences were first discovered in the threshold analysis results in which findings suggested that edge effect point density is significantly different between monocot and dicot species. Intensity values alone did not provides significant variation in species to classify between plants. Upon this discovery mapping data and known positional data for the combinational trial suggested that in applying these thresholds as discrimination factors a distribution map of monocot density is an accurate measure of weed presence and abundance (**Table 27)**. With this information we can accept the hypothesis that through structure and intensity returns of a 532 nm wavelength laser, we are able to differentiate between monocot and dicot species while also classifying the species densities.

CHAPTER VI

SUMMARY AND FUTURE STUDY

There is a gap of knowledge concerning the control of weeds in *Brassica napus* L. crop systems and the control of volunteer *B. napus* in a wheat cropping system in the southern Great Plains that is necessary for proper management and implementation of this crop. The objectives of this project were to determine potential controls of volunteer weeds in *B. napus* cropping systems and herbicide resistant volunteer *B. napus* in wheat cropping systems and the application of a new precision farming tool: Terrestrial Laser Scanning (TLS) to discriminate crops from weeds and map their locations and abundance. We found that application of Potassium salt of Glyphosate had a significant impact ($P \leq 0.05$) on weed control in *B. napus* cropping systems. We also found that Flufenacet and Bromoxynil herbicides were found to be significantly best ($P \leq 0.05$) in control of volunteer *B. napus* in a wheat cropping system when compared to untreated control trials. The intensity values of TLS were found to be effective in discriminating monocot weeds in a *B. napus* cropping system or discrimination of volunteer *B. napus* in a wheat cropping system. It was also possible to detect mustard in experimental plots using height partition technique.

In review it is evident that more work should be done to determine potential applications of other herbicides in a canola herbicide tolerant cropping system. This is due to the potential of outcrossing of this tolerance trait to weedy relatives (Beckie et al., 2003; Begg et al., 2006; Légère, 2005; Warwick, 1991). Also after analysis of effective herbicides in the control of a glyphosate resistant canola, it is clear that many herbicides can be effective, so future studies in this area should include a cost analysis project to the most economical chemical for application. As for future work with the new technology terrestrial laser scanning, our study found a discrimination method between dicots and monocots, but this method could potentially not be feasible in a dual monocot scenario. This could also be the case in a system in which the dicot has a smaller leaf structure than that of the canola which was the dicot in this study. More work is necessary to determine if this method is acceptable in multiple species combinations.

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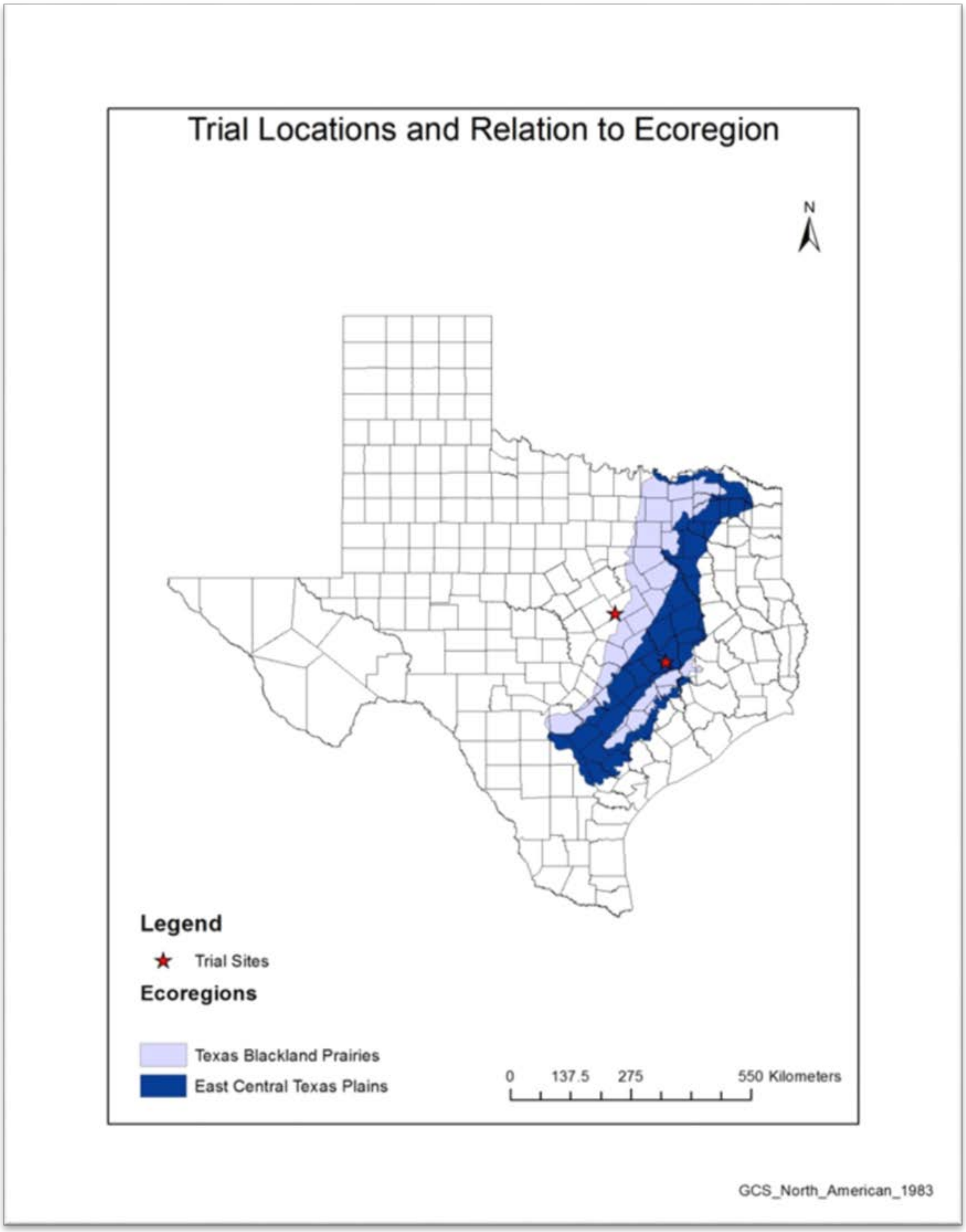
APPENDIX A

Location of trial sites and their relation to Eco regions in Central Texas.



APPENDIX B

In field data acquisition using Terrestrial Laser Scanning. Operator controlling scanning unit through graphical interface and geo-referenced target positions distributed in field for spatial correction.

APPENDIX C

Illustration of weed distribution map in which monocots are considered the weed. The classification is done on a high to low classification according to weed density within the give cell. Points represent know species positions that are used for accuracy assessment.